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Double-Skin Facade in Low-Latitude: Study on the Absorptance, Reflectance, and Transmittance of Direct Solar Radiation

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ABSTRACT

This paper presents the absorptance, reflectance and transmittance of double-skin façade in low-latitude area. The calculation of absorptance, reflectance, and transmittance was done by numerical simulation using a model of double-skin facade. The results shows that reflectance, absorptance, and transmittance of solar radiation in double-skin façade are varying based on the angle incidence. When the angle incidence is lower than 70°, the percentage of transmittance, reflectance and absorptance of the solar radiation is low and relatively constant. The percentage of reflected solar radiation will increase rapidly and the percentage of absorbed and transmitted solar radiation will decrease when the solar incidence angle is higher than 70°.

Keywords: Double-skin façade, absorptance, reflectance, transmittance

1. Background

Double-skin façade is a concept for reducing energy consumption in building, this applies the façade technology to reduce cooling and heating loads. It comprises of outer and inner glasses, which form a cavity space. Between outer and inner glasses, there are a shading device and air space. At the bottom of the cavity, there is a lower aperture, as well as upper aperture on the top of the cavity. These apertures are operable for open and close to allow natural ventilation applied to the cavity.

Double-skin façades have proven to be efficient at reducing building energy consumption particularly heating loads in winter and cooling loads in summer, and they have been successfully applied in cold and temperate climates. However, there is currently insufficient information for designing a double-skin façade that can be used in a hot and humid climate such as Indonesia's.

Since the location of Indonesia is in the tropic-equator, the application of double-skin façade shall be benefit in reducing solar heat gain. Solar altitude in the equatorial lane may reach the higher position up to 90°. As the result, the solar incidence may also reach the higher degree. Higher degree of solar incidence would be benefit for the building façade since large amount solar radiation could be reflected.

This paper presents the simulation result of the Study on the absorptance, reflectance, and transmittance of direct solar radiation using a double-skin façade model.

2. Literature Review

2.1. Definition of double-skin façade

The double-skin façade is different from conventional double and triple glazed façades, and it characterized by the passage of air through the cavity air space between the inner and the outer

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glasses. Double-skin façades are further differentiated from conventional double or triple glazed façades by the passage of air through the cavity between the inner and outer skins. The movement of air is an important departure from more standard glazing systems such as double and triple glazed insulating units. The thermal mechanisms are different as are the impacts on energy and comfort. The façade can no longer be envisioned as a static object. Air moves through it modifying and at times dominating its performance characteristics (Lancour et al., 2004).

Waldner, et al. (2007) define a double skin façade as a traditional single façade doubled inside or outside by a second, essentially glazed façade. A ventilated cavity – with a depth from about 10 centimeters at the narrowest to 2 meters for the deepest accessible cavities – is located between these two skins. The cavity can be ventilated with natural, mechanical or hybrid ventilation. Roelofsen (2002) stated that the double-skin façade is ventilated with outside air and allows the ventilation of outside air through open able windows - even in high-rise buildings without causing any nuisance.

2.2. Classification of double-skin facade

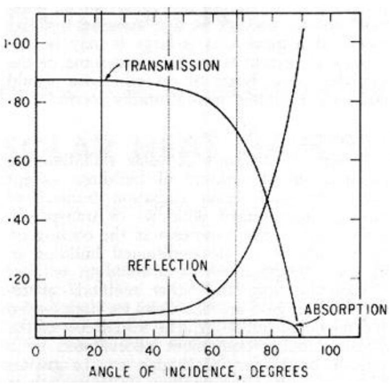
The Belgian Research Institute in Lancour et al. (2004) gives a useful classification of ventilated double-skin façade. The ventilated double-skin façade can be classified based upon three criteria; (1) the type of ventilation, (2) the partitioning of the façade, and (3) the modes of ventilation of the cavity.

The type of ventilation refers to the driving forces at the origin of the ventilation of the cavity located between the two glazed façades. Only a single type of ventilation characterizes each ventilated double skin façade concept. One must distinguish between the three following types of ventilation (Waldner, et al., 2007):

a. Natural ventilation, which is relies on pressure differences without the aid of powered air movement components.
b. Mechanical ventilation employs the aid of powered air movement components.
c. Hybrid ventilation (mix between natural and mechanical ventilation), lies in a control compromise between natural ventilation and mechanical ventilation. In general, natural ventilation is used as far as possible. The mechanical ventilation is only triggered when the driving forces of natural ventilation become inadequate and no longer make it possible to achieve the desired performances. A control system permits the shift from one type of ventilation to other in an automatic and controlled manner based on a control algorithm. It should be noted that few ventilated double façades use this type of ventilation.

2.3. Reflection, absorption and transmission of solar radiation according to the incidence angles

The angle of solar incidence affects to the amount of solar radiation reflected, absorbed and transmitted by the glass into the indoor. When solar radiation falls on the glass, some of solar radiation is reflected, some is absorbed by the glass, and some is transmitted into the indoor (English, 1990). Consequently, the higher position of solar altitude is the higher reflection and the lower transmission of solar radiation into the indoor (Figure).



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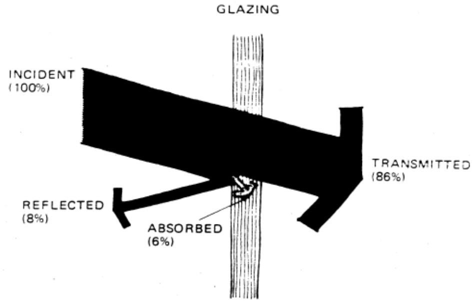
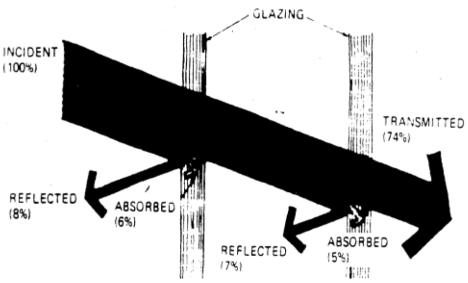
Source: (English, 1990)
Figure 1: Variation of reflection, absorption and transmission of solar radiation by a single glass according the incidence angles



Source: (English, 1990)
Figure 2: Percentage of solar radiation reflected, absorbed, and transmitted on a single-glass

When solar incidence is perpendicular to the ordinary glass surface, the amount of 8% of solar radiation is reflected, 6% is absorbed and 86% is transmitted by the single glass (English, 1990) as can be seen at Figure 2. In pair-glass (double-glass), the outer glass could reflect 8%, and absorbs 6% of solar radiation. The inner glass could reflect 7%, and absorbs 5% of solar radiation. The rest of solar radiation is 74% transmitted into the indoor (see Figure).



Source: (English, 1990)
Figure 3: Percentage of solar radiation reflected, absorbed, and transmitted on a pair-glass

3. Methodology

3.1. Numerical model

The model consists of five storeys with single sheet glass as outer and inner glasses. Between the outer and inner glass, there are horizontal blinds attached as shading device. At the bottom of double-skin, there is a lower aperture for airflow inlet as well as upper aperture on the top of double-skin for airflow outlet.

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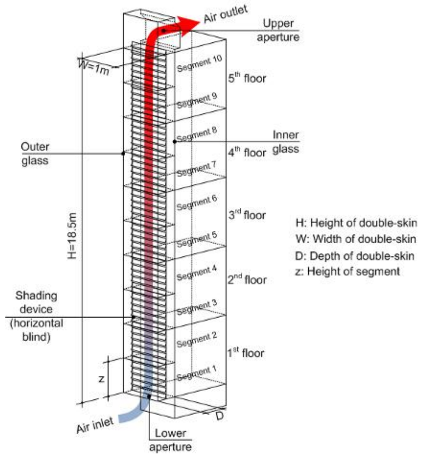
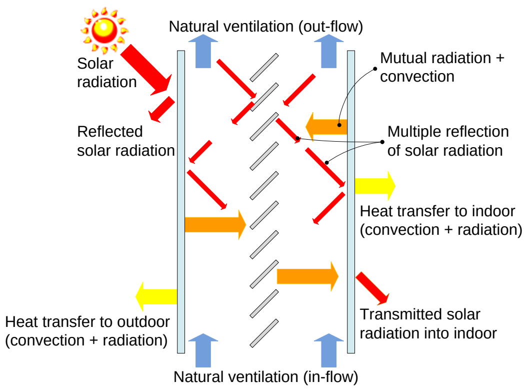


Source: (Mulyadi, 2012)
Figure 7: Model of double-skin façade

The outer glass, the inner glass, the blinds, and the layer of air (which constitute the double-skin façade) were divided into a finite number of segments height-wise. The heat-transfer in each layer was taken into account for the heat balance of each segment. Radiation, multiple reflections of solar radiation, and mutual radiation were considered. For the glass, the incident angle of direct solar radiation and the transmittance, reflectance, and absorptance ratios were taken into account. For the blinds, the variation in the absorption rate and upward and downward transmissions are changed by the profile angle of the blinds due to direct solar radiation, diffuse radiation, and ground reflection. Figure show the heat balance at each segment.



Source: (Mulyadi, 2012)
Figure 5: Heat balance at each segment

The numerical calculation flowchart can be found at Figure . The first step of calculation flow is the input of design condition. In this step, the thickness of the glass, emissivity, transmissivity and absorbsivity of the glass and blinds, the high and width of the double-skin, the depth between the outer glass and blinds, the depth between the blinds and inner glass, the inclination and azimuth angles related to the position of the double-skin, the dimension and coefficient of the airflow rate of the lower and upper apertures, and the ground reflectance were all taken into account.

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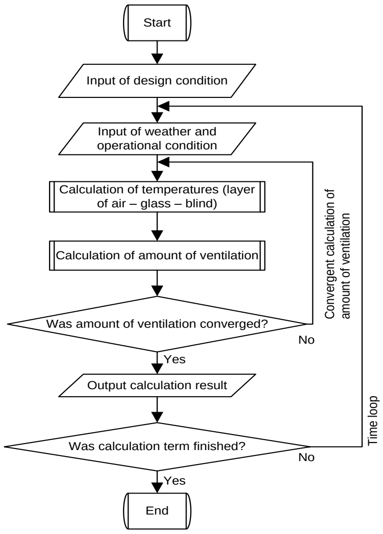

Source: (Mulyadi, 2012)
Figure 6: Numerical calculation flowchart

The next step is the input of weather and operational condition of double-skin. The weather components that inputted are outdoor temperature, global radiation, direct solar radiation, diffuse solar radiation, including solar altitude and solar azimuth. The inputs of operational conditions of double-skin are indoor setting temperature, air-conditioning mode (0: no air-conditioning, 1: cooling mode, 2: heating mode), and presence of shading device (0: no shading, 1: shading is used).

3.2. Design and operational condition

The design conditions of the double-skin, the operational scheme, and the weather conditions were considered. The thickness of glasses, the emissivity and transmissivity of the glasses, the absorbsivity of the blinds, the height and width of the double-skin, the depth between the outer glass and the blinds, the depth between the blinds and the inner glass, the inclination and azimuth angles related to the position of the double-skin, the dimension and coefficient of the airflow rate of the lower and upper apertures, and the ground reflectance were all taken into account (see Table 1).

Table 1: Design and operational condition of the numerical model

Physical properties	Value
Azimuth angle of North-facing double-skin [°]	0
Azimuth angle of East-facing double-skin [°]	90
Azimuth angle of South-facing double-skin [°]	180
Azimuth angle of West-facing double-skin [°]	270
Inclined angle of double-skin [°]	90
Distance between outer glass and blinds:	
▪ for 200 cm width of double-skin [cm]	190
▪ for 150 cm width of double-skin [cm]	140
▪ for 100 cm width of double-skin [cm]	90
▪ for 80 cm width of double-skin [cm]	70
Distance between blinds and inner glass [cm]	10
Slat angle of blinds [°]	45
Solar transmittance rate of blinds [-]	0.1
Solar absorption rate of blinds [-]	0.5
Emissivity of blinds [-]	0.95
Emissivity of glass [-]	0.837
Flow coefficient of lower and upper apertures [-]	0.65
Area of lower and upper apertures [m^2/m]	0.30
Ground reflectance [-]	0.14

Source: (Mulyadi, 2012)

3.3. Absorptance, Reflectance, and Transmittance of Solar Radiation

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The amount of total solar radiation received at the surface of double-skin I_{DS} are depend on direct normal radiation *DN* [W/m^2], incident angle to the window surface *i* [°] , glass surface area ratio to the sunshine *SG* [-], sky horizontal radiation *SH* [W/m^2], tilt angle to the window surface γ [°], global radiation TH [W/m^2] , and ground reflectance ρ_{gr} [-].

$$I_{DS,total} = DN\cos i \times SG + SH\cos^2\left(\frac{\gamma}{2}\right) + TH\left[1-\cos^2\left(\frac{\gamma}{2}\right)\right]\times \rho_{gr} \quad \text{Eq. 1}$$

The amount of direct solar radiation absorbed at the outer glass $I_{a,og,D}$ is obtained from the amount of direct solar radiation ID [W/m^2] multiplied by the absorption rate of the outer glass $\bar{\alpha}_{og,D}$ and can be written as follows,

$$I_{a,og,D} = \bar{\alpha}_{og,D} \times I_D \quad \text{Eq. 2}$$

where,

$$\bar{\alpha}_{og,D} = \alpha_{og,D}\left[1+\tau_{og,D}\frac{\rho_{sd}\left(1-\rho_{sd}\rho_{ig,D}\right)+\tau_{sd}^2\rho_{ig,D}}{\left(1-\rho_{og,D}\rho_{sd}\right)\left(1-\rho_{sd}\rho_{ig,D}\right)-\rho_{og,D}\rho_{sd}^2\rho_{ig,d}}\right] \quad \text{Eq. 3}$$

where $\bar{\alpha}_{og,D}$ is absorption rate of direct solar radiation at the outer glass, $\tau_{og,D}$ is the transmittance rate of direct solar radiation at the outer glass, ρ_{sd} is the reflectance rate of the shading device, $\rho_{ig,D}$ is the reflectance rate of direct solar radiation at the inner glass, τ_{sd} is the rate of direct solar radiation transmitted by the shading device, $\rho_{og,D}$ is the reflectance rate of direct solar radiation at the outer glass.

The amount of direct solar radiation absorbed in the shading device $I_{a,sd,D}$ obtained from the amount of direct solar radiation I_D multiplied with the absorption rate of the shading device $\bar{\alpha}_{sd,D}$ as seen at the equation below,

$$I_{a,sd,D} = \bar{\alpha}_{sd,D} \times I_D \quad \text{Eq. 4}$$

$\bar{\alpha}_{sd,D}$ is obtained from,

$$\bar{\alpha}_{sd,D} = \tau_{og,D}\alpha_{sd}\frac{1-\rho_{sd}\rho_{ig,D}+\tau_{sd}\rho_{ig,D}}{\left(1-\rho_{og,D}\rho_{sd}\right)\left(1-\rho_{sd}\rho_{ig,D}\right)-\rho_{og,D}\tau_{sd}^2\rho_{ig,D}} \quad \text{Eq. 5}$$

where $\tau_{og,D}$ is the transmittance rate of direct solar radiation at the outer glass, and α_{sd} is the absorption rate of the shading device.

The amount of direct solar radiation absorbed in the inner glass $I_{a,ig,D}$ takes into account the absorption rate of direct solar radiation at the inner glass $\bar{\alpha}_{ig,D}$ multiplied with the amount of direct solar radiation I_D as can be seen in the equation below

$$I_{a,ig,D} = \bar{\alpha}_{ig,D} \times I_D \quad \text{Eq. 6}$$

$\bar{\alpha}_{ig,D}$ is obtained from,

$$\bar{\alpha}_{ig,D} = \tau_{og,D}\tau_{sd}\alpha_{ig,D}\frac{1}{\left(1-\rho_{og,D}\rho_{sd}\right)\left(1-\rho_{sd}\rho_{ig,D}\right)\left(\rho_{og,D}\tau_{sd}^2\rho_{ig,D}\right)} \quad \text{Eq. 7}$$

where $\alpha_{ig,D}$ is absorption rate of the inner glass.

The amount of direct solar radiation that is reflected by the double-skin $I_{ref,D}$ is taken from the amount of reflection rate $\bar{\rho}_D$ of direct solar radiation multiplied by the direct solar radiation as can be seen in below equation,

$$I_{ref,D} = \bar{\rho}_d \times I_D \quad \text{Eq. 8}$$

$\bar{\rho}_D$ was taken from,

$$\bar{\rho}_D = \rho_{og,D} + \tau_{og,D}^2\frac{\rho_{sd}\left(1-\rho_{sd}\rho_{ig,D}\right)+\tau_{sd}^2\rho_{ig,D}}{\left(1-\rho_{og,D}\rho_{sd}\right)\left(1-\rho_{sd}\rho_{ig,D}\right)-\rho_{og,D}\tau_{sd}^2\rho_{ig,D}} \quad \text{Eq. 9}$$

The amount of direct solar radiation transmitted by double-skin $I_{tran,D}$ is equivalent to the amount of direct solar radiation I_D multiplied by transmittance rate $\bar{\tau}_D$ as can be seen at the equation below,

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$$I_{tran,D} = \bar{\tau}_D \times I_D \quad \text{......Eq. 10}$$

$\bar{\tau}_D$ can be obtained from,

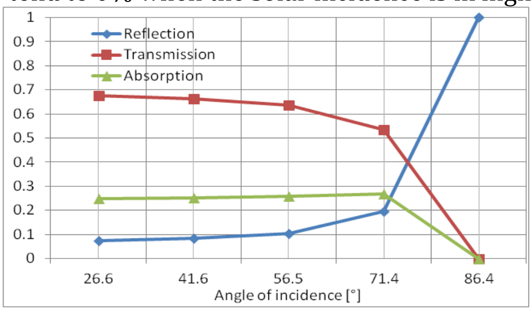
$$\bar{\tau}_D = \tau_{og,D}\tau_{sd}\tau_{ig,D}\frac{1}{(1-\rho_{og,D}\rho_{sd})(1-\rho_{sd}\rho_{ig,D})-\rho_{og,D}\tau_{sd}^2\rho_{ig,D}} \quad \text{......Eq. 11}$$

where $\tau_{ig,D}$ is the transmission rate of direct solar radiation through the inner glass.

4. Results and Discussions

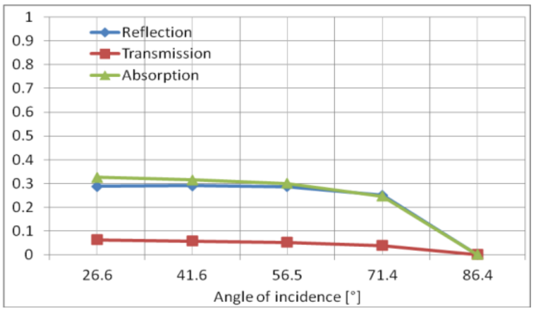
The amount of reflectance, absorptance, and transmittance of solar radiation is varying according to the altitude and incident angle of the sun. In double-skin façade, the amount of solar radiation reflected, absorbed, and transmitted are different to the outer glass, shading device, and inner glass.

As can be seen at Figure and Figure , variation of the reflectance of solar radiation is gradually increase until the angle of incidence reach to more than 70°, and increased rapidly to 100% as the solar incidence is raise when get near to 90°. While, variation of absorptance and transmittance is decrease tend to 0% when the solar incidence is in high position.



Source: (Mulyadi, 2012)

Figure 7: Variation of reflection, absorption and transmission of solar radiation on the outer glass of a double-skin façade at March 8 according the incidence angles



Source: (Mulyadi, 2012)

Figure 8: Variation of reflection, absorption and transmission of solar radiation on the shading device of a double-skin façade at March 8 according the incidence angles

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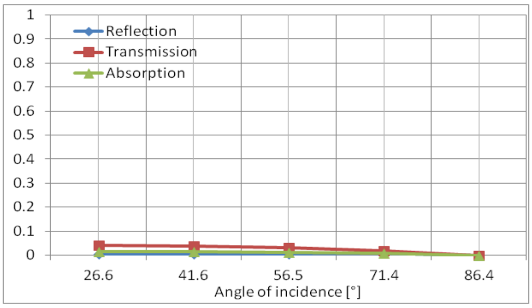
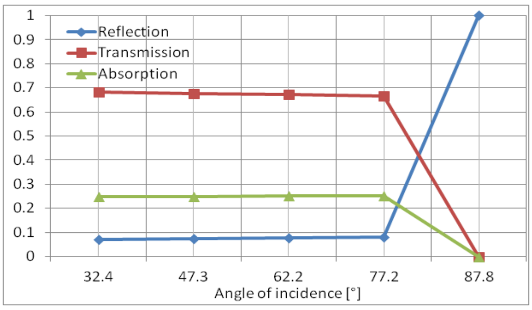
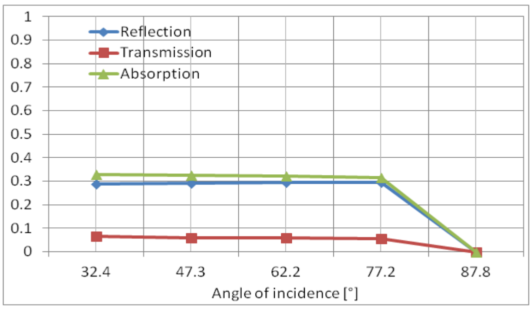


Source: (Mulyadi, 2012)
Figure 9: Variation of reflection, absorption and transmission of solar radiation on the inner glass of a double-skin façade at March 8 according the incidence angles



Source: (Mulyadi, 2012)
Figure 10: Variation of reflection, absorption and transmission of solar radiation on the outer glass of a double-skin façade at October 9 according the incidence angles



Source: (Mulyadi, 2012)
Figure 8: Variation of reflection, absorption and transmission of solar radiation on the shading device of a double-skin façade at October 9 according the incidence angles

Source: (Mulyadi, 2012)
Figure 9: Variation of reflection, absorption and transmission of solar radiation on the inner glass of a double-skin façade at October 9 according the incidence angles

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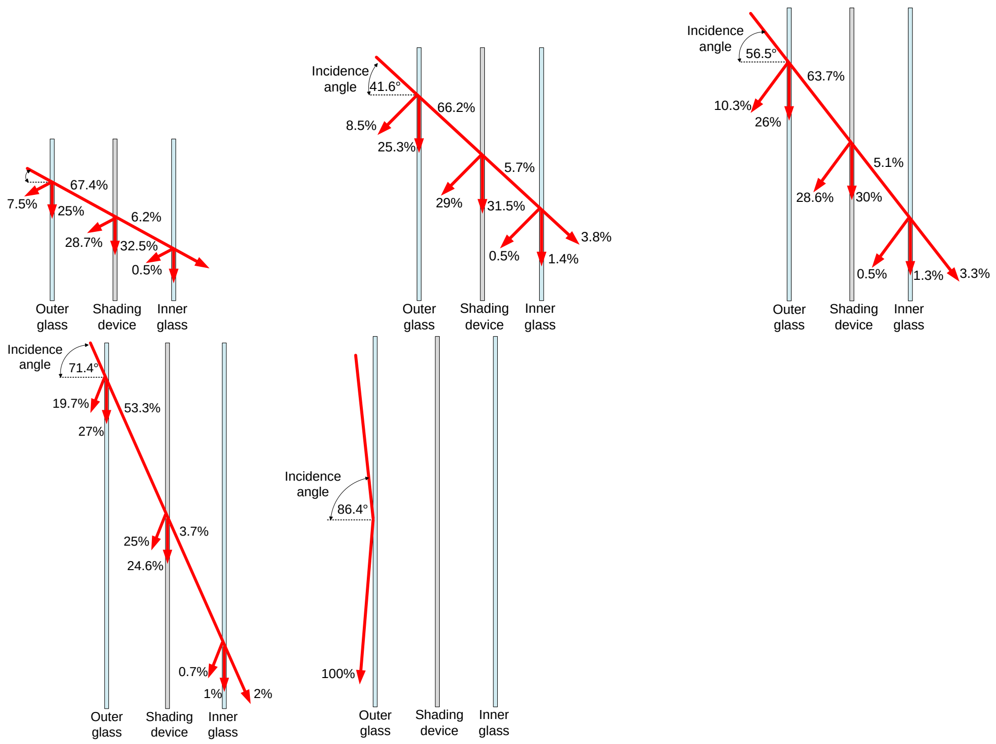

Source: (Mulyadi, 2012)

Figure 10: Percentage of reflection, absorption, and transmission in relation to the angle of incidence of solar radiation on double-skin façade at March 8

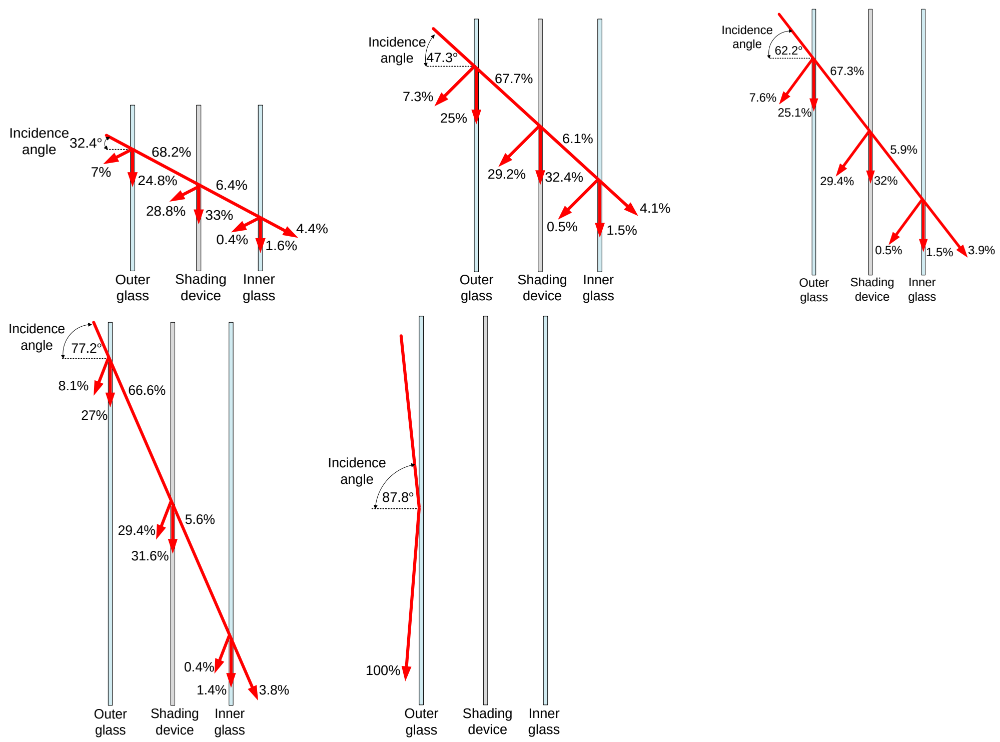

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Figure 14: Percentage of reflection, absorption, and transmission in relation to angle of incidence of solar radiation on double-skin façade at October 9

Variation of reflectance, absorptance, and transmittance of solar radiation on the shading device is slightly different with the outer glass. In the outer glass, large amount of solar radiation is transmitted before the solar incidence reach to more than 70°. In shading device, most of solar radiation is reflected and absorbed (see Figure , Figure , Figure , and Figure 8). The amount of reflection, absorption, and transmission of solar radiation on the inner glass is relatively low and reach 0% when the solar incidence higher than 80° (refer to Figure and Figure 9).

The percentage of incident solar radiation reflected from the glass depends on the property of the glass and the angle of incidence. As can be seen on Figure 10 and Figure , percentage of reflected of solar radiation is lowest when the solar incidence at low degree of angle. At the higher degree of incidence angle of solar radiation (87.8°), the solar radiation completely reflected by the outer glass of double-skin façade without absorbed and transmitted. Reflectance is important in term of solar heat gain because it represent the net heat loss from the indoor.

In double-skin façade, the shading device has the higher percentage of absorption of solar radiation compared to the outer and the inner glasses. Absorbed radiation warms the material (glass and blind) and transmits it by convection into the indoor. The capacity of the material to absorb solar radiation depend on the distance of the radiation has to travel in the material. The outer and the inner glasses have the thinner layer than the shading device, therefore, the outer and the inner glass is less absorption capability than the shading device. Moreover, the traveling distance of radiation in the material also determined by the direction of incident radiation. When the incident angle of radiation is higher, the absorption will increase as the result of distance factor.

Transmission of solar radiation in the outer glass of double-skin is considered higher than transmission in the shading device and the inner glass. The outer glass of double-skin façade relatively transmits more than 60% of solar radiation into the double-skin's cavity. The transmittance of solar radiation will decrease gradually as the solar incident angle increase.

5. Conclusion

Reflectance, absorption, and transmission of solar radiation in double-skin façade are varying based on the angle incidence of solar radiation. When the angle of incidence is lower than 70°, the percentage and absorptance of the solar radiation increased gradually, while the percentage of transmission decreased gradually. The percentage of reflected solar radiation will increase rapidly and percentage of absorbed and transmitted solar radiation will decrease rapidly when the solar incidence angle higher than 70°.

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